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OPERATOR INTERFACE ASSESSMENT FOR THE SENSOR FUSION FLIGHT DEMONSTRATION PROGRAM

Gilbert G. Kuperman

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CREW SYSTEMS DIRECTORATE
HUMAN ENGINEERING DIVISION

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FOR THE COMMANDER

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Multiple sensors were flown during an avionics integration flight demonstration. A millimeter wave radar with an automatic target cuer was employed to perform real-time concealed critical mobile target detection. Forward looking infrared and laser line scan sensors were used to support target confirmation. An operator interface was designed and evaluated by operational command subject matter experts. An automated sensor management system was used to reduce crew workload.

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PREFACE

This effort was conducted under exploratory development Work Unit 7184 10 44, "Advanced Strategic Cockpit Engineering and Research," by personnel of the Crew Station Integration Branch, Human Engineering Division, Crew Systems Directorate, of the Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. The Sensor Fusion Flight Demonstration (SFFD) project, which is the broader context within which the reported research was conducted, was sponsored by the Theater Missile Defense Office of the Aeronautical Systems Center, Wright-Patterson Air Force Base, Ohio (ASC/YXT). Lt Col D. Bostelman (ASC/YXT) served as the management focal point and Mr W. Moyer (ASC/YXT) provided technical direction for the SFFD project.

Special thanks are due to the highly professional and knowledgeable personnel of the Strategic Air Command (SAC) who served as subject matter experts in support of the SFFD project. Additional thanks are due to Maj B. J. Aller (HQ SAC) for freely contributing his expertise in the area of flight test planning, to Capt J. Sato (HQ SAC) for her guidance in requirements and tactics to hold critical mobile targets at risk, and to Maj A. Sobel for her assistance in performing SFFD crew task decompositions.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

GLOSSARY

AGL	Above ground level
ASD	Aeronautical Systems Division
ATC	Automatic target cuer
ATR	Automatic target recognizer
DIR	Downward-looking infrared
DMA	Defense Mapping Agency
DTED	Digital terrain elevation data
E	Mental effort (SWAT)
FAR	False alarm rate
FLIR	Forward-looking infrared
FOV	Field-of-view
FRZ	Freeze frame display mode
ft	Feet
G	Giga
HR	Hit rate
HVP	High value point
Hz	Hertz
INS	Inertial navigation system
IP	Initial point
IRIG	Interrange instrumentation group
GPS	Global positioning system
km	Kilometer
Kts	Knots
LADAR	Laser radar

LLS	Laser linescan
LOC	Line of communication
m	Meter
MMWR	Millimeter wavelength radar
MOP	Measure of performance
MPD	Multipurpose display
mr	Milliradian
N	Narrow
Nm	Nautical mile
OI	Operator interface
Pixel	Picture element
Pro-SWAT	Projective SWAT
PTP	Programmable touch panel
RCS	Radar cross section
S	Psychological stress (SWAT)
SA	Situational awareness
SAC	Strategic Air Command
SFFD	Sensor fusion flight demonstration
SME	Subject matter expert
SMS	Sensor management subsystem
SWAT	Subjective workload assessment technique
T	Time stress (SWAT)
TDC	Target designation cursor
TEL	Transporter/erector/launcher
TH	Track handle
W	Wide

WPT	Waypoint
^{o}	Degree
μm	Micrometer

Section I

INTRODUCTION

BACKGROUND

The Sensor Fusion Flight Demonstration (SFFD) project was initiated in December 1990 under the sponsorship of the Mobile Target Office of the Aeronautical Systems Division (ASD), Wright-Patterson Air Force Base, Ohio. The overall intent of the project was to demonstrate an increased Air Force capability to locate concealed and/or camouflaged targets (Stephens, 1992). The SFFD project had two specific objectives:

1. The fusion of data from two or more sensors in determining if a potential target site was, in fact, occupied, and
2. Real-time route planning integrated with the multiple sensor system.

An associated sub-objective was to assess the capability of the aircrew member in exploiting the SFFD system concept in the execution of a series of concealed target search tactics.

Prior to the initiation of the SFFD project, ASD had sponsored several single sensor flight demonstration activities as part of the GLITTER PAGEANT program. These sensors included synthetic aperture radar, millimeter wavelength radar (MMWR), forward- and downward-looking infrared (FLIR, DIR), and laser linescanners (LLS) and radar (LADAR). Imagery from the GLITTER PAGEANT collections was used to assess the potential utility of

each sensor class and to support the development and demonstration of automatic target cueing and recognition (ATC/ATR) algorithms and systems. Building on these single sensor demonstrations, the SFFD project was initiated to allow the Air Force to explore the potential utility of integrated, multiple sensors. It was intended to serve as an intermediate concept leading to the future flight demonstration of a fully developed sensor fusion concept (Toms and Kuperman, 1991). This "building block" approach (single sensors, followed by multiple sensors, leading to sensor fusion) was viewed as a way of conducting an advanced development program which would minimize the cost, schedule, and technical risks associated with the future engineering manufacturing development of an operational system concept (Peio, Crawford, and Kuperman, 1991).

The SFFD project was conducted by the Boeing Defense and Space Group, Seattle, Washington. A Boeing 757-200 aircraft was specially modified to serve as the SFFD platform. It was equipped to support a variety of advanced avionics effectiveness demonstrations, several of which were combined to form the SFFD avionics concept. All SFFD flight activity took place at the Ft. Lewis Washington Army National Guard training ranges located in the Ranier Military Operations Area (South of Olympia, Washington).

A series of six Air Force-sponsored SFFD flights were conducted during the period of 22 April through 7 May 1992. The targets of interest were M-1 Abrams main battle tanks and

surrogates for theater missile transporter/erector/launchers (TELs). Actual tanks, positioned by the Washington Army National Guard, were either uncovered or masked with camouflage nets. The "TELs" were large transport vehicles (garbage trucks) and were similarly treated. In addition, unoccupied camouflage nets were also deployed. They were intended to serve as decoys. Each of the six flights consisted of approximately 18 passes through the target area. All passes were conducted at a nominal altitude of 1,200 ft AGL and at a ground speed of approximately 205 kts indicated airspeed.

HUMAN FACTORS ISSUES

The SFFD project represented a unique opportunity to gain insight into two areas related to the design and evaluation of the operator interface (OI) for a crew-aided, multiple sensor, target acquisition system. First were those issues related to the design of the OI itself. These were divided into four sequential areas:

1. Providing situational awareness (SA) information to the crewmember prior to the target search and confirmation segments of the flight.

2. Providing SA and mission pacing information to the crewmember during the target search and confirmation segments.

3. Providing a decision support capability during the target confirmation segment.

4. Providing a decision support capability during the

weapon assignment segment.

The second, related area of human factors concern was the utility of the OI in supporting the crewmember during the actual prosecution of the mission.

The major objectives were embodied in several very specific human factors engineering contributions to the SFFD project.

Section II

SYSTEM CONCEPT

SFFD SUBSYSTEMS

The SFFD avionics suite includes a MMWR with an associated ATC, a FLIR, and a LLS, together with an on-board Sensor Management Subsystem (SMS). Figure 1 presents the basic avionics concept embodied in the SFFD project.

Mission Planning: Ground-based mission planning is performed to limit the area to be searched for potential targets. Lakes, swamps, and other non-trafficable terrain is excluded from the search area. The remaining area is subdivided and prioritized with regard to search value on the basis of accessibility to lines of communications (LOCs, i. e., roads or trails), degree of terrain slope, availability of vegatative masking (e. g., treelines), etc. Further, mission planning takes into account the type of search to be performed, the sensor(s) to be employed, and the direction(s) in which they are to be pointed in order to achieve an unobscured line of sight to each potential target site. The output of the mission planning process is a data base of single or multiple sites (i. e., "high value points," HVPs) to be visited by the SFFD aircraft and sensors.

Navigation and Flight Management: The testbed aircraft avionics complement includes both an Inertial Navigation System (INS) and a Global Positioning System (GPS) airborne terminal. The combined INS/GPS navigation reference serves as a highly accurate

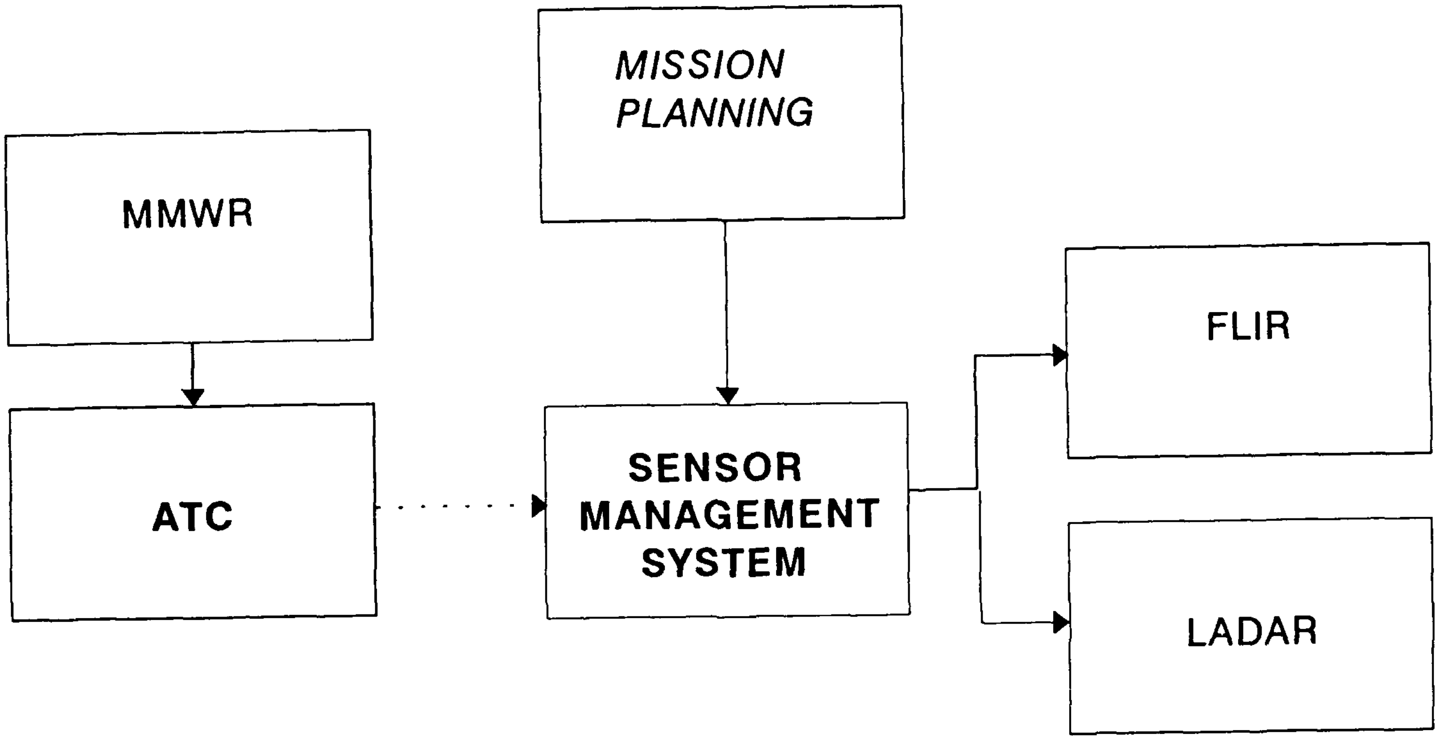


Figure 1. SFFD System Concept

determinant of aircraft position and supports the SFFD SMS in obtaining sensor coverage of preselected points. The INS/GPS system is coupled into the 757's autopilot to provide automated horizontal steering commands. The pilot maintained manual control of aircraft flight altitude.

MMWR: The MMWR was developed by the Boeing High Technology Center (Henderson, 1990). It serves to provide a low altitude, adverse weather search capability. It is a 35 GHz frequency, real beam mode radar. It is operated as a frequency-modulated, continuous wave radar. It is reported to have an effective range from in excess of 10 nm down to 100 meters, with two km being the effective range for the SFFD flights. It exhibits a beam width (one-way) of 2.4° and a range resolution of 0.5 m out to 2 km. The MMWR scans a swath of $\pm 30^{\circ}$ directly in front of the SFFD aircraft.

ATC: The signal from the MMWR is fed directly into an ATC. The ATC algorithms (developed during prior reseach and development programs) were refined to correspond to the target set and backgrounds of interest to the SFFD project. The radar cross section (RCS) of the tank was estimated to be about 50 m^2 while the RCS of the surrogate TEL was approximately three times as great. The MMWR ATC was used to detect possible targets (i. e., objects exhibiting an RCS significantly greater than that arising from background clutter sources).

FLIR: A FLIR Systems Incorporated Model 2000B FLIR sensor was employed as one of the two target identification sensors

demonstrated in support of the SFFD project. This sensor employs a two by four element time-delay-integration array of mercury-cadium-telluride detectors to detect long wave length infrared energy in the eight to 12 μm spect^ral band. It is a dual field of view (FOV) sensor. The wide (W) FOV is 28^{o} horizontal by 15^{o} vertical, while the narrow (N) FOV (achieved using 5.6 magnification telescope lens), is 5^{o} horizontal by 2.4^{o} vertical. The NFOV was employed from its maximum slant range down to a minimum slant range of 2500 ft at which point the FLIR switched to WFOV. Resolution of the FLIR is reported to be 2.7 mr in the WFOV mode and 0.25 mr in the NFOV. The FLIR images 320 active lines per frame which are converted into a conventional 525 TVL per frame video display format. The FLIR is gimbal-mounted and its FOV may be directed in both azimuth ($\pm 60^{O}$) and elevation to any point on the ground, under the command of the SMS.

The expected image quality of the FLIR was a factor which limited the SFFD flight altitude. The FLIR was considered to be more suitable for security surveillance purposes than for tactical target acquisition. However, it was available to the SFFD project while higher quality FLIRs were not. The FLIR gimbals also proved to be a limitation on SFFD flight profiles. Although rated to a much higher value, the gimbals demonstrated a maximum airspeed limitation of 205 kts; this was the airspeed adopted for all SFFD flights.

The FLIR images were presented to the operator in a freeze frame display format. The ground locations for the FLIR images

were determined either by a) "intelligence" estimates of HVPs (i. e., likely locations for the deployment of the prebriefed target types, based on capability and tactical doctrine assumptions) or b) MMWR/ATC target detections for which the SMS was able to schedule a FLIR imaging event.

<u>LLS</u>: The LLS, produced by Hughes-Danbury Optical Systems (formerly Perkin-Elmer Corporation), was employed as a second SFFD identification sensor. It employs a gallium arsenide laser (8.5 μm wavelegth) together with a silicon avalanche photodiode detector to acquire passive (emittance), active (specular reflectance), and/or height (range) images over a $\pm 60^{\circ}$ swath centered on the aircraft nadir line. This provides approximately $\pm$ 1,500 ft of cross track ground coverage when the aircraft is at an altitude of 1,000 ft AGL.

In essence, in the LLS active mode, the spot on the ground being illuminated by the laser beam is simultaneously imaged by the detector. The LLS has a reported resolution of 20 mr in the cross track direction by 5 mr along track. Because it is essentially downward-looking, the LLS offers some measure of robustness against terrain-masked ground targets. The LLS was expected to be useful against camouflaged and concealed targets because of the three dimensional nature of the range image and the possibility of penetrating signature denial netting.

The LLS images were presented to the operator in a freeze frame display format. The LLS digital format is 2048 picture elements (pixel) across track (i. e., in the scan direction) by

however long the along track path might be. A conventional, real-time display of line scan sensor imagery is frequently in the form of a "waterfall" format. LLS forward coverage is provided by the forward motion of the aircraft. The scan rate is controlled so that each individual scan line is just contiguous with the preceding line. (This results in avoiding both "holidays" and oversampling in the ground coverage.) In a "waterfall" format, the newest scan line is presented at the top of the display, with prior lines shifted toward the bottom. In the SFFD implementation, however, the SMS controlled an image extraction step. A video frame grabber captured a 2048 by 2048 pixel full area image from the "live" LLS video. The SMS determined the location of a sub-image area, corresponding to 512 by 512 pixels, which was centered on the target location. This 1/16th area sub-image was presented in freeze frame in a conventional 525 TVL video format.

The ground locations for the LLS sub-images were determined either by a) "intelligence" estimates of HVPs (i. e., likely locations for the deployment of the prebriefed target types, based on capability and tactical doctrine assumptions) or b) MMWR/ATC target detections for which the SMS was able to schedule a LLS imaging event. LLS images, presented to the operator, were within $\pm 47^{\circ}$ of perpendicular to the nadir line.

The power of the LLS laser limited the effective range of the SFFD flights and resulted in the nominal altitude of 1200 ft AGL. A more powerful laser would have supported higher flight

altitudes. Again, the LLS was available to the SFFD project.

SMS: The SMS, described by Wilber (1991) and Lammers (1992) and depicted in Figure 2, provided multiple capabilities to the SFFD system. Once ground-based mission planning has produced a set of prioritized HVPs, the SMS logic was used to generate a sensor management plan. The SMS included what was, in essence, an expert system to control the FLIR. This process was intended to maximize the number of HVPs actually imaged by the FLIR and to also optimize the quality of the imagery obtained. The first stage of the mission planner established a straight-line aircraft ground track whick brought the aircraft into proximity to the maximum number of HVPs. The computations required to assure imaging the maximum number of HVPs were dominated by the slew rate capability of the FLIR gimbals. The aircraft position, current FLIR pointing direction, range to the HVP, desired sensor FOV, the number of images desired at the HVP, the location of any already scheduled FLIR images subsequent to the current HVP, etc., were included in determining if and when a HVP would be imaged by the FLIR. In many cases, the azimuthal range over which a HVP could be imaged was restricted. This was also taken into consideration. Basically, the sensor plan was built on the timing required to slew the FLIR between successive HVPs. Planning for LLS coverage was much simpler. The HVP was either within the LLS FOV or it wasn't. If it was, then a LLS image was scheduled for display to the operator.

During the SFFD flights, the SMS provided active control

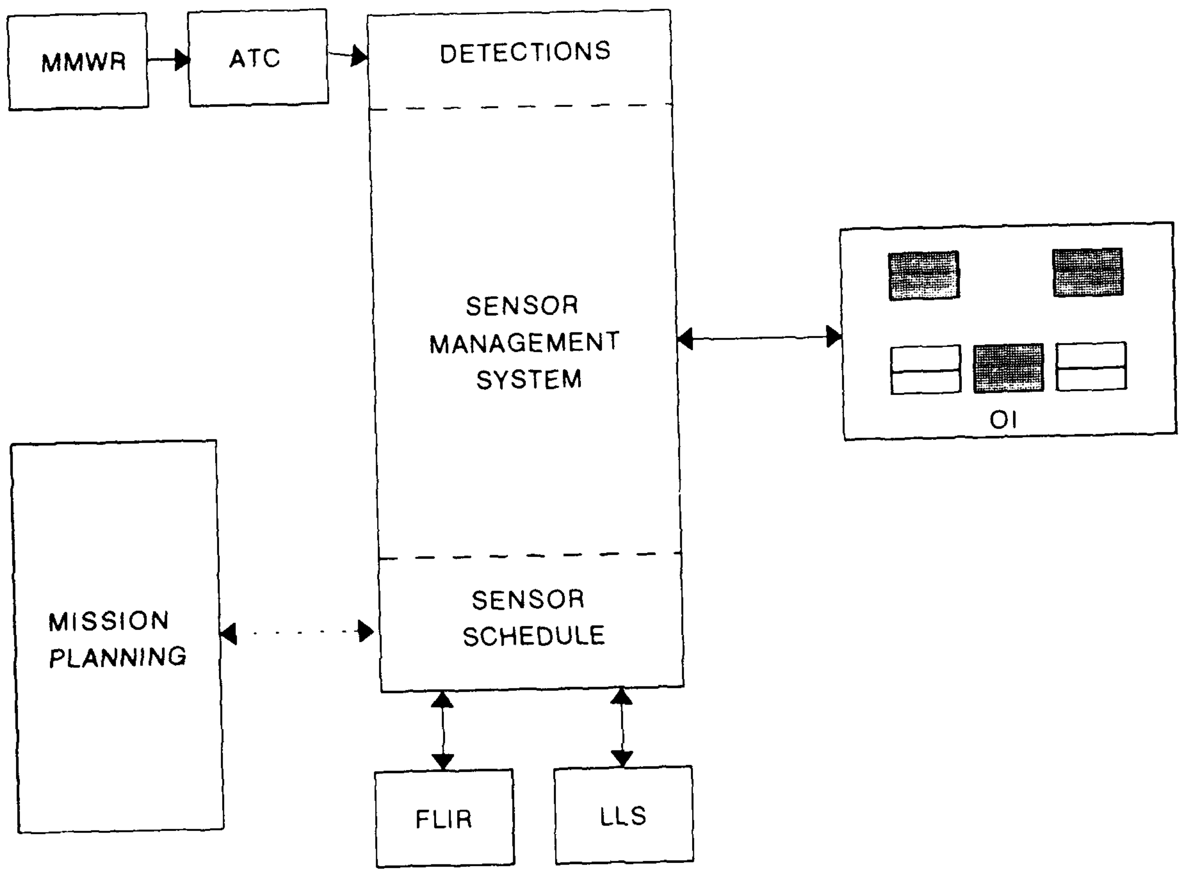


Figure 2. SFFD Sensor Management System

over FLIR pointing and LLS image display to the operator. Following the established sensor plan, the SMS directed the FLIR to each HVP location. When the MMWR/ATC provided a real-time detection, the sensor planner function of the SMS performed a real-time rescheduling of FLIR pointing. Once a detection was received by the SMS, it first attempted to correlate the location of the detection with an existing HVP location in the sensor plan. If the detection location was already scheduled for sensor coverage, the SMS did nothing further. If the detection was at a new location, then the SMS attempted to schedule sensor coverage of that location. Priority was given to the preplanned HVPs, based on the a priori "intelligence" estimates, over the MMWR/ATC declarations. Again, sensor gimbal rates determined whether the SMS could incorporate the new image request into the existing sensor plan without deleting other preplanned sensor coverage. This capability of being able to automatically integrate MMWR detections as real-time additions to the sensor plan allowed the SFFD to demonstrate dynamic retasking. (The origin of the requests for additional sensor coverage were essentially transparent to the SMS. They could, as easily, have originated from any of a number of on-board or off-board cueing or detection sensors.)

The SMS also served to support two other SFFD functions. During the target confirmation phase, the SMS managed the data base of images the operator judged to contain possible targets. During the weapon allocation phase, the SMS managed the image

data base and supported the operator in performing a target prioritization/weapon assignment function.

TACTICS

Figure 3 depicts a notional SFFD mission phase. It is composed of three types of activity: prior to the initial point (pre-IP), search, and post-search. The multiple sensors and SMS support a variety of search tactics. Figure 4 depicts these tactics. Mission planning has established the aircraft track as generally parallel to a LOC. The MMWR can cover the entire stretch of road included in this search area, as can the LLS. (If the MMWR/ATC results in a detection, then the FLIR could be slewed by the SMS to acquire a confirmation image.) Multiple FLIR images can be planned and commanded to accomplish search along tree lines or over local areas. Individual HVPs can, of course, be imaged. Because of the accuracy of the SFFD navigation system, FLIR images can be commanded to look into road cuts, fire breaks, and other interruptions in tree lines.

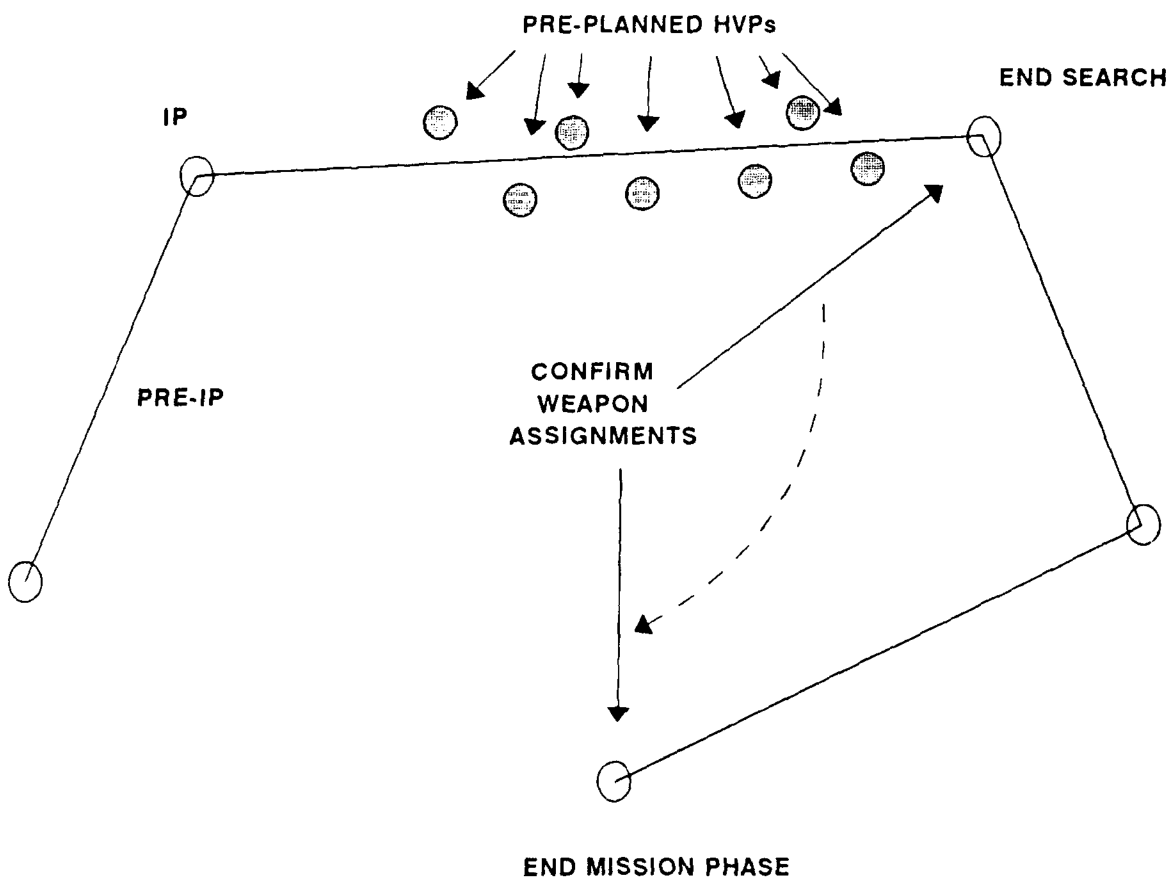


Figure 3. Notional Sequence of SFFD Events

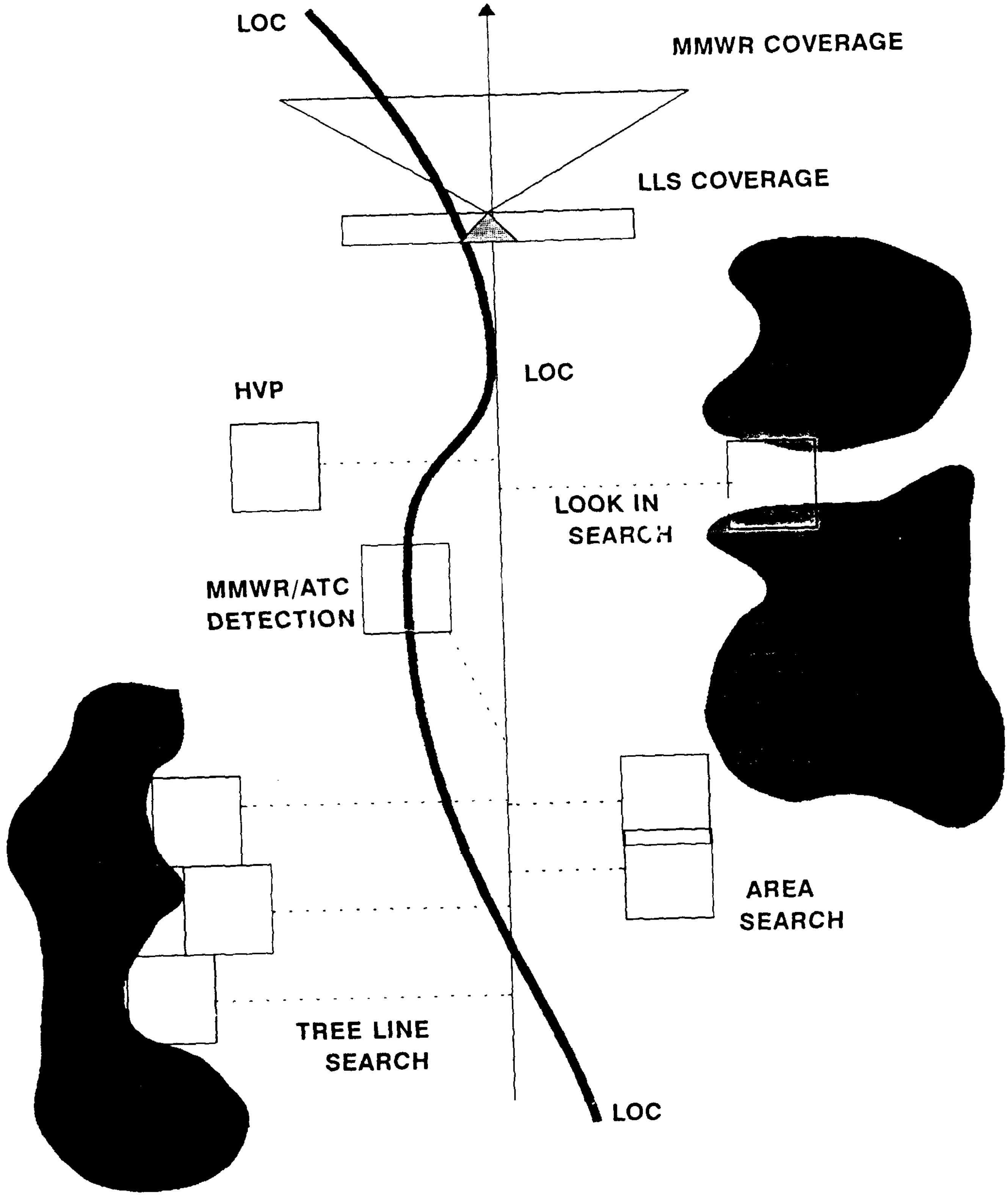


Figure 4. SFFD Tactics

Section III

OPERATOR INTERFACE

SFFD CREW STATION

The SFFD crew station (the OI) consisted of three multipurpose displays (MPDs) as information sources and four programmable touch panels (PTPs) as control input devices (shown in Figure 5). The LLS imagery was always presented on MPD 1 and was always in freeze frame mode (FRZ). MPD 1 was controlled by PTP 1. The FLIR imagery was always presented on MPD 2 and was always FRZ. MPD 2 was controlled by PTP 2. MPD 3 was used for several purposes. During the pre-IP segment, MPD 3 was configured to present a depiction of the planned route and preplanned imaging events, i. e., HVPs (similar to Figure 3).

There is also a track handle (TH) located at the crew station. It is used to select a "display of interest" from between the three MPDs, to control the position of a target designation cursor (TDC), and as a "hands on" controller for selecting/deselecting individual items of information. (The specifics of the TH control functions are presented in the context of the individual crew tasks which require them.)

CREW TASKS

Pre-IP: During the pre-IP phase, the operator verified the configuration of his crew station, assuring himself that the

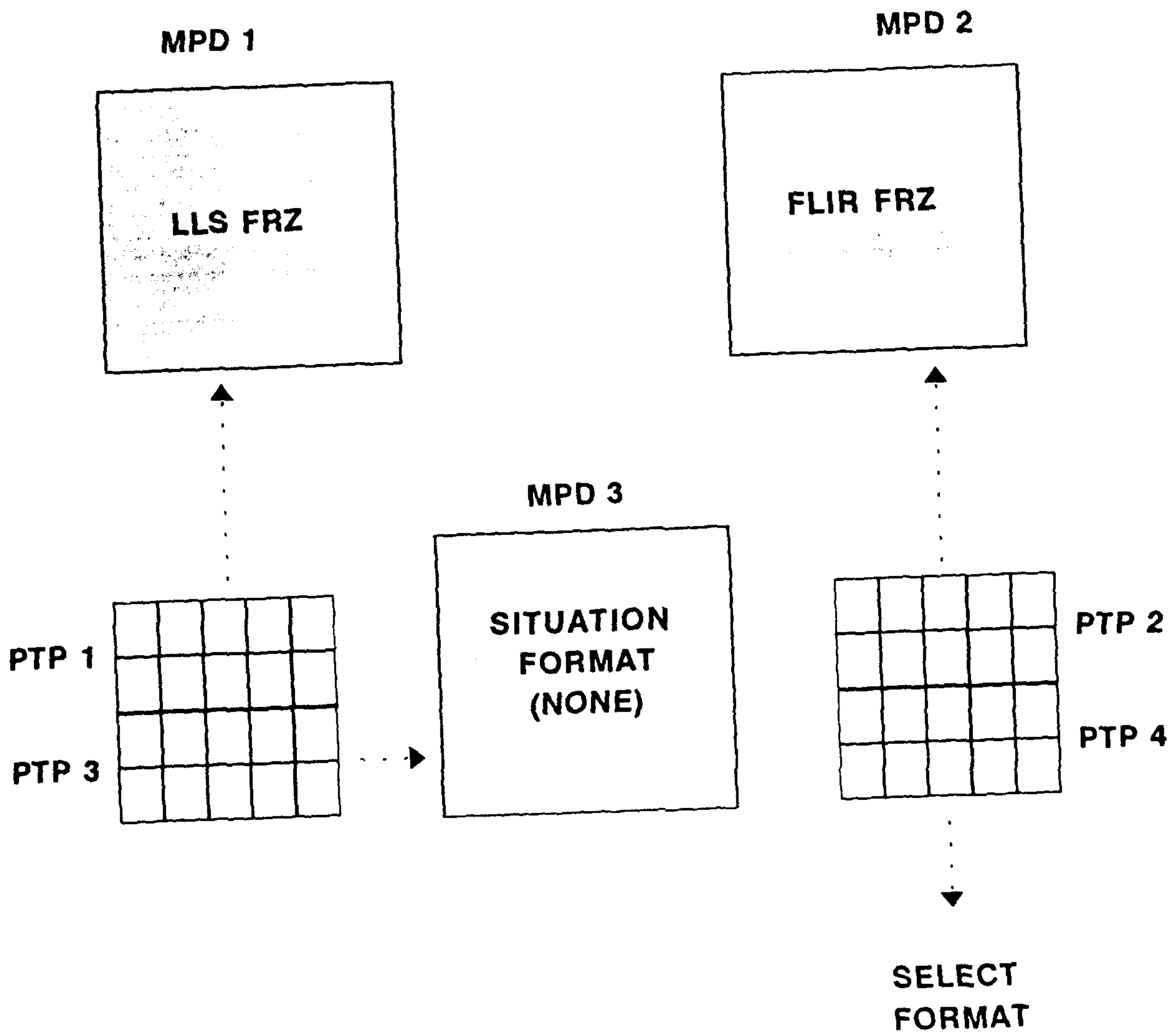


Figure 5. SFFD Operator Interface

required information sources were presented on the appropriate display surfaces. (The use of a "school solution" crew station configuration was intended to avoid variation in crew performance due to differences in information availability.) He also reviewed a hardcopy "enroute strike folder" (an annotated line drawing of the flight track from pre-IP through End Mission Phase. The hardcopy stike map was annotated to show local airfields and towns. (These were "gamed" as "keep out" or "threat avoidance" areas in the scenario.) Range/bearing information was provided alongside each flight leg and at each start turn point.

The operator could also review the sensor management plan during the pre-IP leg. He could note how many images to expect and in what order and with which sensor combination to expect them. This information was presented on the Sensor Plan display format which was an alternative information display on MPD 3 (lower MPD). The Sensor Plan format was accessed (on MPD 3) through the use of PTP 4. Figure 6 depicts the PTP formats employed to invoke the Sensor Plan. First, the operator would depress the SENSOR DATA button on the Select Format PTP screen. This action invokes the Select Screen menu on the PTP. The operator would depress SCREEN 3 to activate the Sensor Plan format on MPD 3.

Figure 7 depicts the Sensor Plan format. The top left of the format presents SA information. The aircraft is shown to be enroute to waypoint (WPT) 7 which is 6.6 nm distant. The

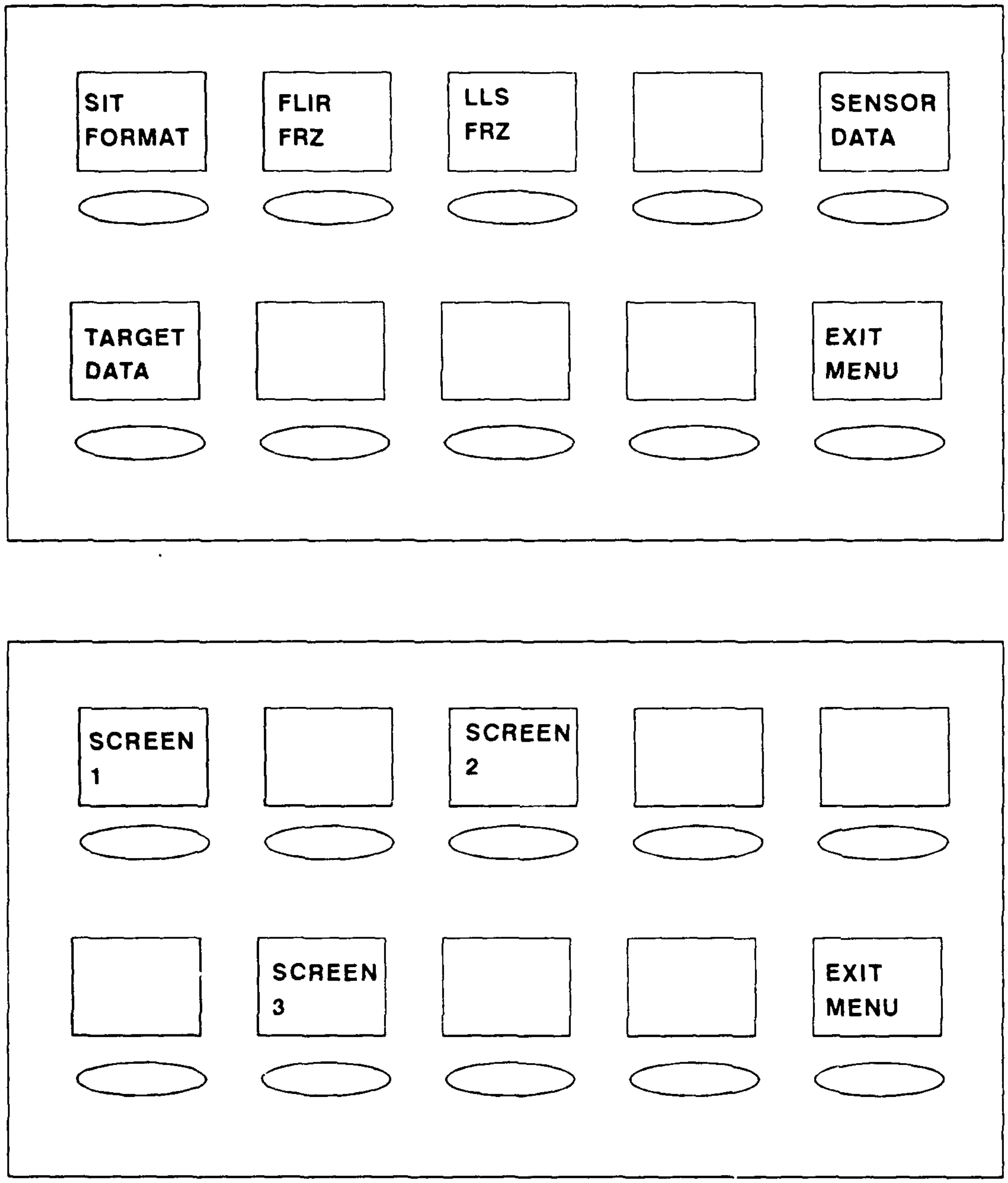
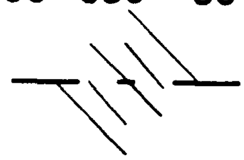


Figure 6. PTP Controls for Select Format and Select Screen Functions

WPT: 7	DIST: 6.6	TTT 00:00	IRIG 00:00:00	00 089 30
	FLIR	LLS		
IMAGE TIME	008	013		
	AUTO	AUTO	PAGE: 1	

SENSOR PLAN	TOTAL: 13	LLS	FLIR	
1 50	A M F L		L1	
2 50	A M F L	I3	L2	
3 50	A M F L	I4		

Figure 7. SFFD Sensor Plan Format

time-to-go until the next preplanned image acquisition event is shown as is the IRIG (Interrange Instrumentation Group) time (H:MM:SS). The top right portion of the format is a graphic presenting the current aircraft attitude. It contains a pitch ladder which also rotates to provide a roll cue (similar to a conventional attitude display indicator instrument) and a heading digital readout. The remainder of the format presents the Sensor Plan data. There are 13 planned image events in this leg, with each event shown on a row in the Plan. The first number in each row (1, 2, 3, ...) identifies the event. The number below the ID number is an SMS-assigned "confidence" or "quality" value. In the Figure, each of these confidences has been (arbitrarily) assigned a value of 50. The value in the Sensor Plan is based solely on confidence in the a priori intelligence that supported the area limitation data base construction of mission planning. A set of four boxed letters (A, M, F, and L) appears in each row. They represent independent information sources and if a box is filled in, it tells the operator that a sensor event is planned. (During the course of the mission, the plan will be updated in real-time, as imaging events actually occur.) The "A" refers to the area limitation analysis and is always filled in since that is how preplanned imaging events are nominated. The "M" refers to the MMWR, the "F" to the FLIR, and the "L" to the LLS. For HVP 1, a single FLIR image is planned (the "F" box is filled in), for HVP 2 both FLIR and LLS images are planned, and for HVP 3 only a LLS image has been scheduled.

IP-to-End Search: During this leg of the mission phase, the operator again performs three types of tasks. He monitors the execution of the sensor plan. The primary information source is the SA display format on MPD 3. Figure 8 depicts this format. The top portion of the SA format contains two graphic counters, one showing the number of image buffers available for storing FLIR images (denoted by the "F") and the other for LLS images. It also presents time and distance information (similar to the Sensor Plan format). The main area of the format shows the current leg of the mission. The aircraft track is shown as are the preplanned sensor points. Points co-located with area limitation points are shown by the addition of a filled circle to an open circle. Color codes are used to highlight the current (next) FLIR and LLS imaging events and to indicate which HVPs will be imaged by a single sensor or by both sensors. Exclusion/"keep out" may also be indicated by graphics. A distance scale is provided for operator reference. The lower portion of the format presents aircraft location, heading, altitude, and ground speed (GS) information, as well as the status of the MMWR (ON/OFF), an attitude and heading reference, and sensor imaging event infomation.

The operator performs occupancy checks of the HVPs as they are imaged. He uses the FLIR and LLS sensor image format screens on MPDs 1 and 2 to support this. These format screens are depicted in Figure 9 and their associated PTP menus are shown in Figure 10. The cursor box shown on the FLIR FRZ format indicates

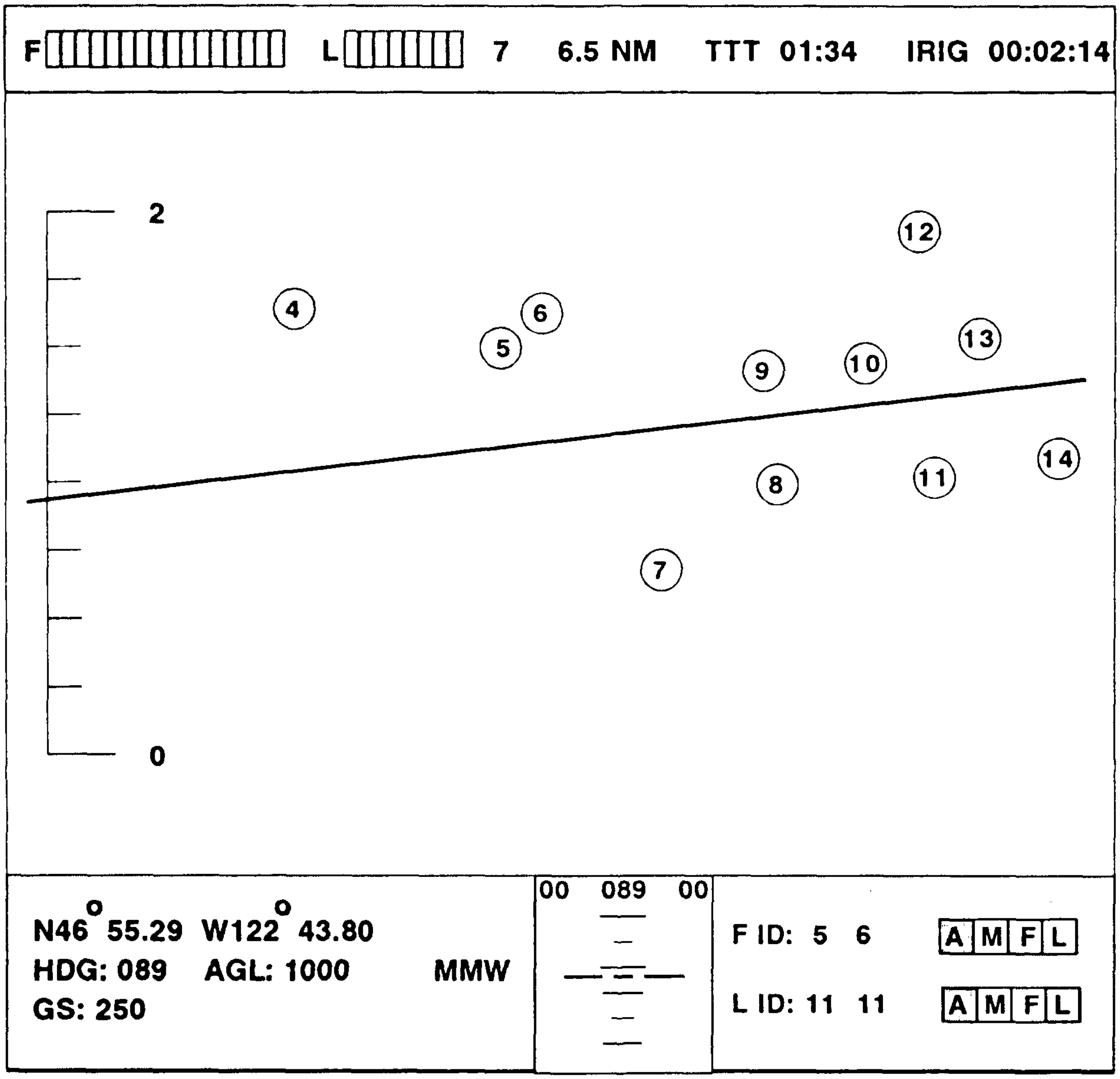


Figure 8. Situational Awareness Display Format

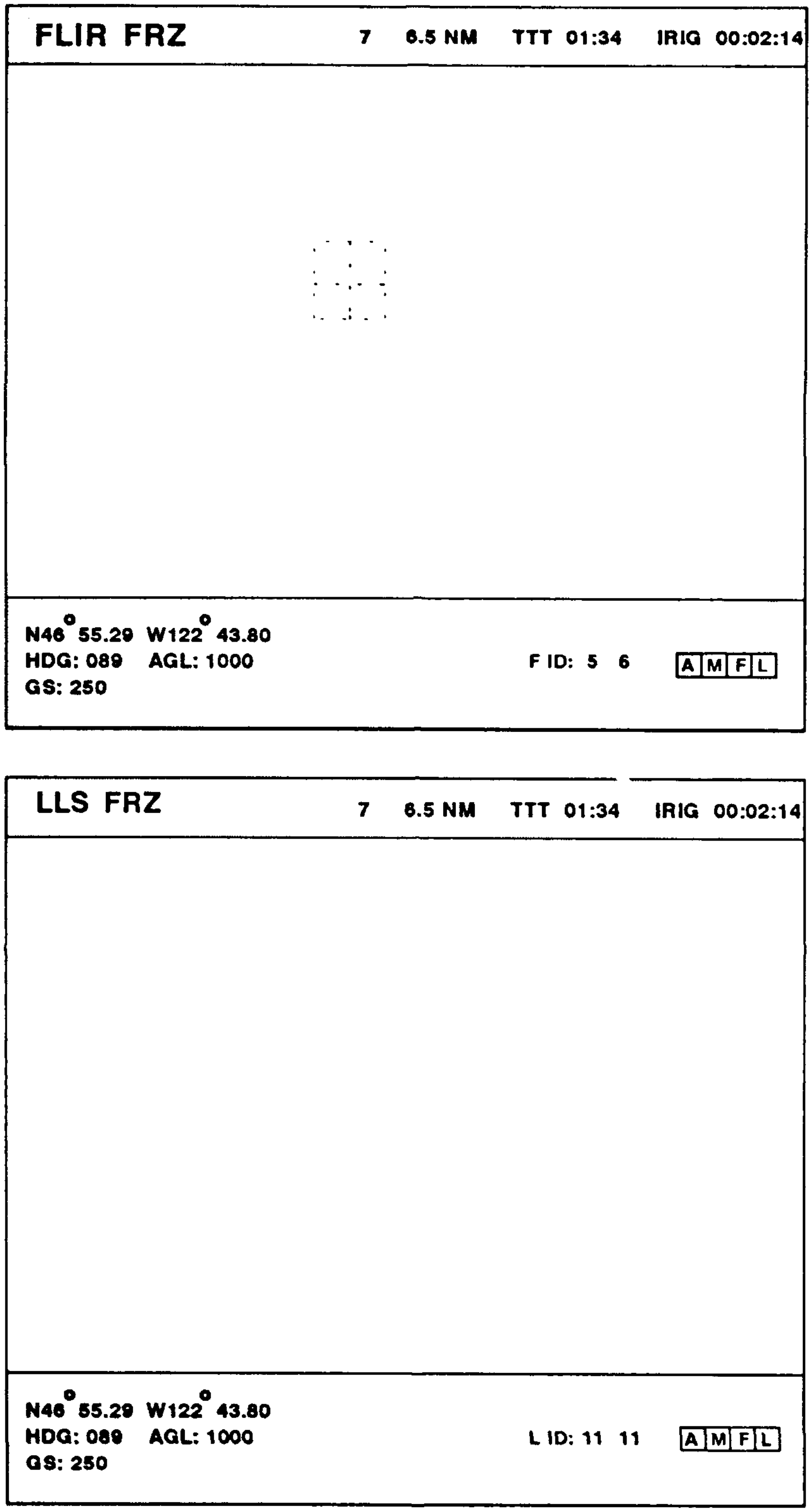
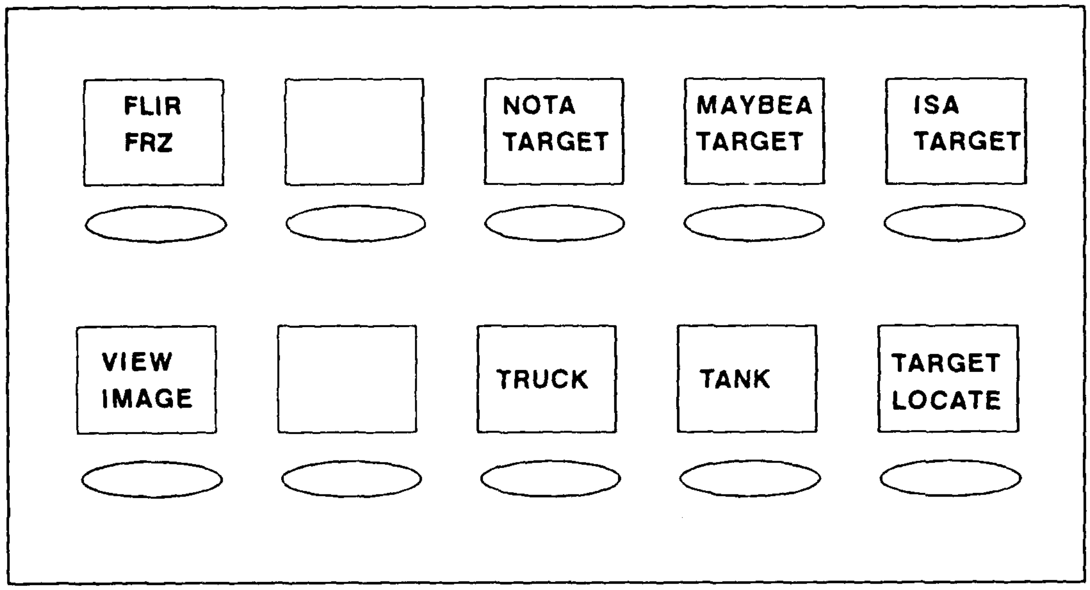


Figure 9. FLIR and LLS Freeze Frame Image Display Screens



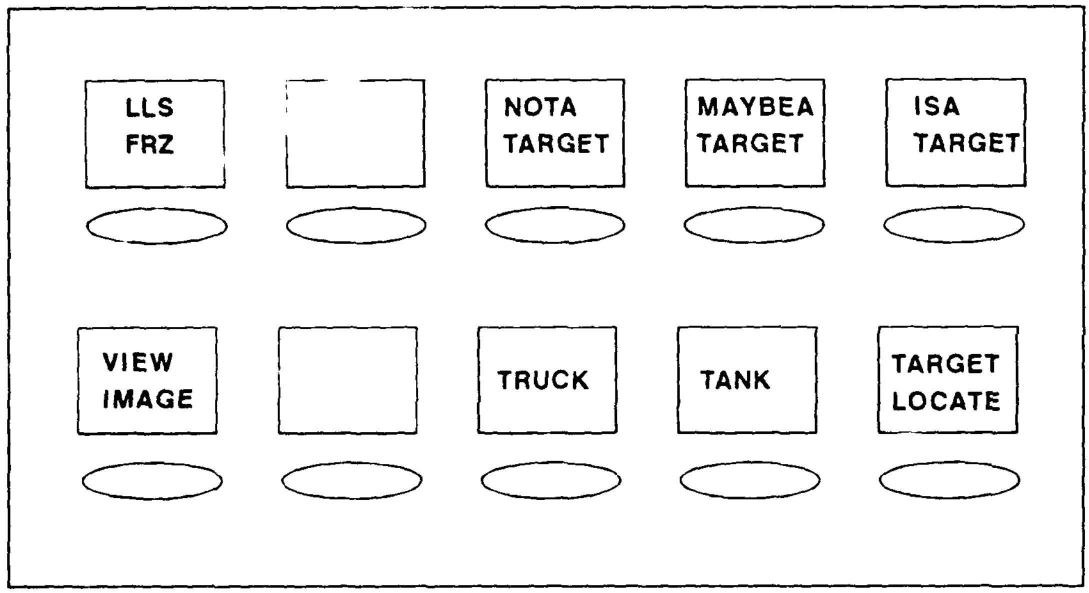


Figure 10. PTP Controls for FLIR and Laser Line Scan Freeze Frame Control

either the location of the HVP (if intelligence-derived) or the location of the MMWR detection (if real-time sensed) within the displayed image. The cursor appears as a graphic overlay to the sensor image. It is under manual control and its location on the MPD is governed by the knurled knob located on top of the TH.

The operator uses the FLIR and LLS freeze frame PTP screen formats to execute the real-time occupancy checks. As images appear on the FLIR and LLS FRZ MPD screens (Figure 9), the operator uses the ISA, MAYBEA, and NOTA TARGET buttons on the appropriate PTP (Figure 10) to input his declaration. (This action also assigns a confidence value to the imaged target. A NOTA TARGET entry has a value of 0, a MAYBEA TARGET entry has a value of 50, and an ISA TARGET entry has a value of 100. These values are entered in the Target Data MPD format screen, described below.) Additional information is presented to the operator regarding the generation of the image. The "A" portion of the A-M-F-L box is filled in if the image is of a preplanned HVP and the "M" is filled in if the image is of a real-time MMWR/ATC target detection. These data elements may help the operator reach his decision.

Having made his (initial) declaration, the operator can depress the NEXT IMAGE button on the appropriate PTP to call-up an image currently stored in buffer. The SFFD system concept has the capability to store eight LLS FRZ images and 16 FLIR FRZ images. ISA and MAYBEA TARGET declaration images are returned to image store buffers. Images for which the operator's declaration

is NOTA TARGET are discarded from the SFFD system. Buffer counters are included in the top portion of the SA Awareness display format (Figure 7).

To some degree, part of the operator's task during this phase of the mission is to manage the image store queue. He should be aware that possible new images might be lost if there is no place for them in image buffer. The image store buffers are depicted on the FLIR and LLS FRZ MDP formats. These counters are updated in real-time as new images are commanded and acquired. They are decremented in real-time as the operator makes NOTA TARGET assignments. The SA and Sensor Plan formats depict how many more images are scheduled. Of course, the MMWR/ATC may generate additional imaging events in real-time. If the image store buffer is filled, no new images will be acquired. Knowing that some target acquisition opportunities might be lost places some additional time stress on the operator.

The third task performed by the operator during this mission segment is to <u>update target locations</u>. This is accomplished by using the cursor control knob on the TH to refine the target location cursor graphic on the MPD. The cursor position is adjusted so that it is superimposed directly over the image of a target vehicle. The trigger switch on the TH is used to capture the refined target location (cursor position) and to transfer it to a stores management subsystem for possible use as a weapon aimpoint.

<u>End Search-to-End Mission Phase</u> During this portion of the

scenario, the operator is concerned with completing any occupancy checks (for images which are still in buffer but which have not yet been reviewed) and with confirming weapon assignments. During this (latter) task, the operator interacts with the SFFD Target Data Format display screen (Figure 11). This format is somewhat similar to the Sensor Plan Format screen (Figure 6) with respect to mission and aircraft attitude information. There are, however, two major differences. The listing of available images now contains those image identifications for which a sensor was actually employed and for which the operator assigned an ISA or a MAYBEA TARGET confirmation response. (The probability or confidence values shown were adjusted based on the operator's prior review. An ISA TARGET response raised the value to 100.) The second new feature of the Target Data Format screen concerns weapon assignments. The SFFD operational concept assumed that six standoff missiles were available for target attack. A Weapon Status indicator, located at the top of this screen, depicts how many weapons have been automatically assigned against confirmed targets. This assignment is made on the basis of the adjusted confidence values. The six targets currently having the highest associated confidences are paired with weapons.

The operator tailors the SFFD OI (using the PTP 4 Select Format and Select Screen commands) to activate the Target Data Format screen on MPD 3 (bottom). An associated TARGET DATA menu of control functions appears on PTP 3. He then employs the TH controls to select an image for review. He does this by using

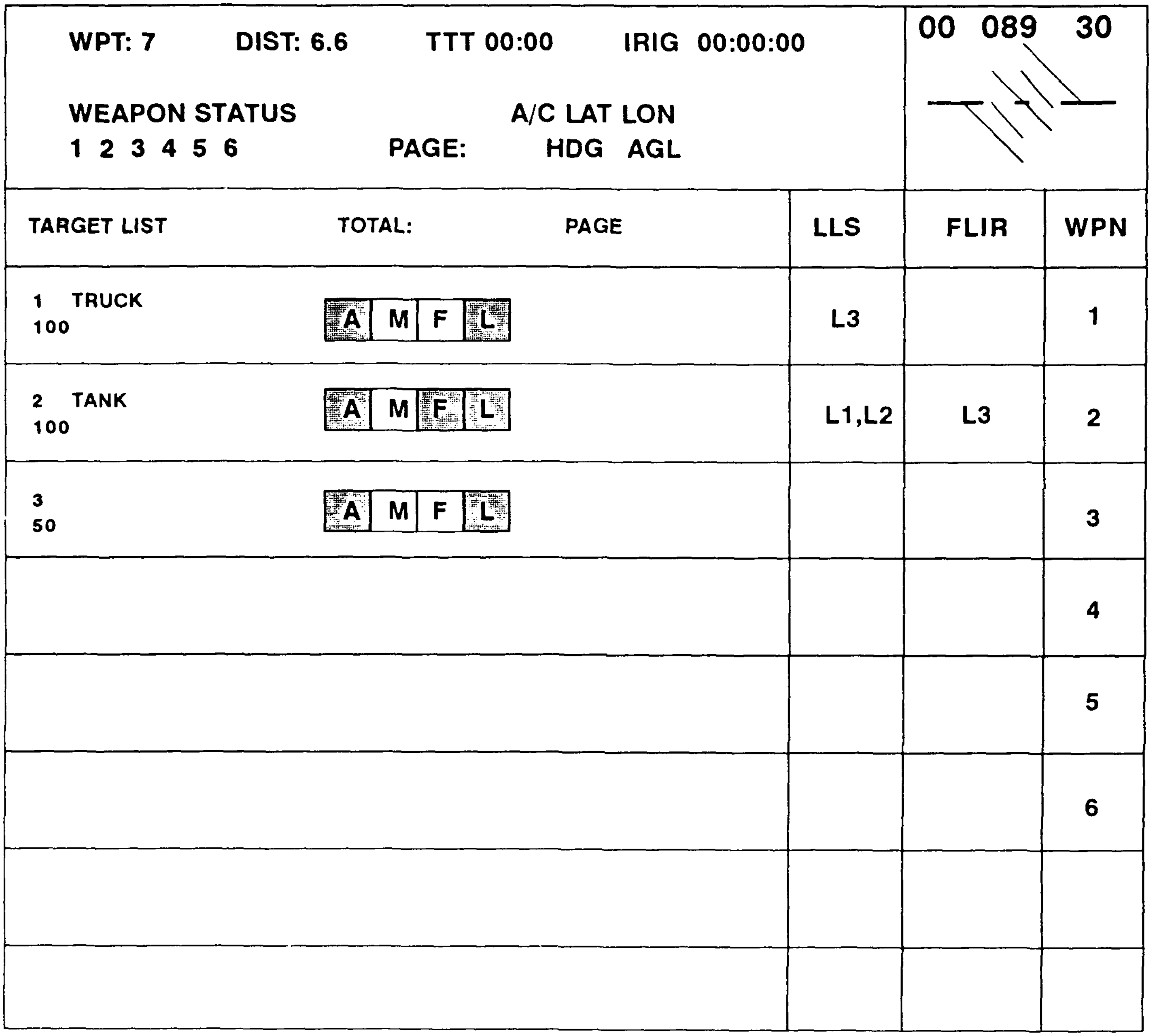


Figure 11. SFFD Target Data Format

the knurled knob on the top of the TH to slew a selection cursor to the Target Data row which presents the information corresponding to the image to be selected. Depressing the TH trigger switch activates of "hooks" the desired imagery. (Again, LLS FRZ imagery appears on MPD 1 and FLIR FRZ images are presented on MPD 2.) Once the target imagery has appeared for his review, he performs image study and target location updating (as above).

The operator can interact with the automated weapon assignments by using the WEAPON OK and WEAPON NOT OK menu items on the Target Data format of PTP 3. If WEAPON OK is invoked, no change occurs. If, however, the operator invokes the WEAPON NOT OK control for an assigned weapon, this has the effect of deselecting that weapon. Two changes to the Target Data Format data occur on MPD 3. The weapon identification number, located in the right hand column of the target data row, disappears and a "free" weapon appears in the Weapon Status area.

The operator can also employ these control functions to nominate new targets for attack. This is essentially a manual override capability within the automated SFFD system concept. The operator uses the TH to hook a target image for which no weapon has been assigned. Again, imagery appears on the MPDs and image review is accomplished. A WEAPON NOT OK input (PTP 3) will leave the weapon aassignment situation unchanged. A WEAPON OK input will, command the assignment of a free weapon against the imaged target. This is equivalent to changing a MAYBEA TARGET

declaration to an ISA TARGET declaration during image review.

Since more images than can appear on one page of the Target Data Format screen could have been retained in long term buffer storage, a PAGE UP/PAGE DOWN function is provided. These controls are included in the TARGET DATA menu on PTP 3.

Section IV

SUBJECT MATTER EXPERTS (SMEs)

SMEs

Seven Strategic Air Command (SAC) rated personnel supported the in-flight demonstration portion of the SFFD project. Three were assigned to SAC Headquarters, Offutt Air Force Base, Nebraska, and the remaining four were assigned to operational SAC units. They were all trained and experienced radar navigators. Six of the seven participated in the project as operators while the seventh served as a "lead operator" during ground school and as an in-flight observer during all demonstration flights. They ranged in bomber flight experience from 2100 to 3800 hours, with a mean of 2571 hours. Strategic aircraft in which this experience was obtained included the B-1B, FB-111A, B-52H, B-2 (avionics testbed), and the SR-71. Six had previous experience using FLIR for navigation or targeting (all with the Electro-optical viewing system in the B-52). This experience ranged from 1800 hours to 2250 hours (with a mean of 1993 hours). Six of the seven had previous experience in laboratory studies directed at evaluating the utility of advanced avionics capabilities for countering critical mobile targets (i. e., mobile missile batteries). The laboratory demonstrations included the concept of a mission management system.

Highly experienced SMEs were desired to assure that they would readily understand the avionics concepts and associated

tactics embodied in the SFFD project. Broad as well as specific experience is required to accomplish the orientation to future concepts with minimum training time and support (Kuperman, 1984). The use of a "lead operator" was also intended to facilitate SME orientation. His role was to serve as an instructor during ground school and refresher training. It was hoped that by receiving training from "one of their own," opportunities for ambiguity or confusion on the part of the SMEs would be reduced to a minimum.

GROUND SCHOOL

Ground school was held at the Boeing facilities, Seattle, Washington, approximately 90 days prior to the actual SFFD flights. It included a combination of classroom and crew station operations practice. The classroom portion covered requirements for finding and attacking critical mobile targets, the SFFD avionics concepts, and mission tactics. During crew station familiarization and practice, the actual SFFD flight equipment was employed in a laboratory (rather than a flight) environment. SMEs were trained in two groups, one week apart, to assure adequate "hands on" experience. FLIR and LLS imagery, obtained during prior test flights, was employed in training to support content validity.

Classroom training topics included an overview of the SFFD project objectives, an overview of the purpose and functioning of the SMS, orientation to the SFFD sensor complement, description

of the demonstration aircraft, description of the SFFD OI, discussion of the workload metrics to be employed, description of the flight profiles, and tours of the SFFD development facility. Two days of OI practice were provided.

REFERESHER TRAINING

Pairs of SMEs participated in SFFD flight demonstrations during three, one week periods. The first day was devoted to refresher training. The objectives of the SFFD project were reviewed. Mission materials and plans were studied. The SMEs were allowed to practice using the OI actually installed in the testbed aircraft. Again, imagery from prior (non-SFFD) flights was used to support SME training.

Section V

MEASURES

BASELINE

Three measures of performance (MOPs) were of particular interest with regard to the demonstration and evaluation of the SFFD OI:

1. The workload experienced by the aircrew in conducting the target search, confirmation, and weapon assignment tasks,

2. The ability of the aircrew (performance) to actually perform these tasks, given the SFFD OI, and

3. The aircrew's assessment of the SFFD OI itself.

Workload was measured by the Subjective Workload Assessment Technique (SWAT). In SWAT, workload is defined as a three dimensional combination of time stress (T), mental effort (E), and psychological stress (S). In practice, SWAT is administered by means of a two-step process: individual scale development and event scoring. During individual scale development, each SME rank orders a set of 27 unique combinations of T, E, S descriptors. Conjoint analysis, a mathematical process, is employed to generate an unidimensional SWAT workload scale over the interval 0 to 100. During event scoring, the SME is prompted to provide a SWAT T,E,S triplet at the completion of each defined task. The SWAT triplet is converted, by table look-up using the individual SME scale, into SWAT workload values.

Performance for the SFFD project, is expressed in terms of the percentage of targets correctly confirmed (hit rate, HR) and the percentage of non-target images incorrectly confirmed by the aircrew (false alarm rate, FAR). These MOPs are calculated based on the FLIR and LLS images cued to the operator as possible target detections (by the MMWR) or as preplanned HVP checks.

The third MOP deals with the assessment of the SFFD OI concept. The instrument employed to quantify this MOP is a set of rating scales. First, the element of the SFFD OI to be assessed is defined. Next, the SME is required to mark a seven point rating scale to indicate how the SSFD OI relates to the design element. (The first, fourth, and seventh demarcations on the scale have semantic anchors associated with them. The left-hand end of the scale is always anchored at a negative response [e. g., greatly detracts from effectiveness], the middle position is always neutral [e. g., neither enhances nor detracts from effectiveness], while the right-hand anchor is always associated with a positive response [e. g., greatly enhances effectiveness].) Lastly, the SME is solicited to provide written comments to substantiate or expand on his rating scale response.

The rating scales dealt with the following SFFD OI areas:

1. Support of SA during the Pre-IP phase
2. Effectiveness of the Sensor Plan Format screen during the Pre-IP phase
3. Effectiveness of the SA Format screen during the target search phase

4. Effectiveness of the LLS FRZ and FLIR FRZ format screens during the target search phase
5. Effectiveness and unambiguity of color coding on the SA Format screen
6. Effectiveness of the Target Data Format screen during the weapon assignment phase
7. Utility of the TH controls during the confirm weapons phase
8. Overall ease of use and crew acceptance of the SFFD OI controls and displays (MPDs, PTPs, TH)
9. Availability of information during the confirm weapons phase
10. Overall adequacy of the size and arrangement of the MPDs and PTPs
11. Preference for freeze frame image presentation versus "live" sensor video
12. Expected acceptance of the SFFD SMS concept by the operational community.

SFFD OI ENHANCEMENT CONCEPTS

The SFFD OI (as described above) was actually employed by the SMEs during the course of the flight demonstration activity. Several additional features of the OI, which might be incorporated in a future SFFD OI design, were demonstrated or described to the SMEs at the conclusion of the in-flight portion

of the project. These were:

1. A counter which tallied the number of times that the SME had viewed a given image (including both the target search and weapon assignment phases of the mission). (This feature had been suggested independently by two of the SMEs during ground school).
2. The addition of eight more image buffers for the storage of LLS FRZ images. (The OI, as flown, could store eight LLS FRZ images and 16 FLIR FRZ images for subsequent SME review).
3. Two types of image underlay on the SA Display Format screen were demonstrated. The first was digital terrain elevation data (DTED) produced by the Defense Mapping Agency (DMA). The DTED was color coded with respect to the terrain elevation. The second underlay approach was based on digitizing color aerial photographs of the Ft. Lewis area.

OPERATIONAL UTILITY ASSESSMENT

The Ft. Lewis range constrained the duration of SFFD flight scenarios. In general, a target search pass was flown in less than two minutes. During the post-mission debrief, the SMEs were shown the mission timeline depicted in Figure 12. In this scenario, target search (as depicted by the rectangular box overlaying the aircraft track) has a duration of five minutes. The SMEs were briefed on two scenarios: a)that there was half

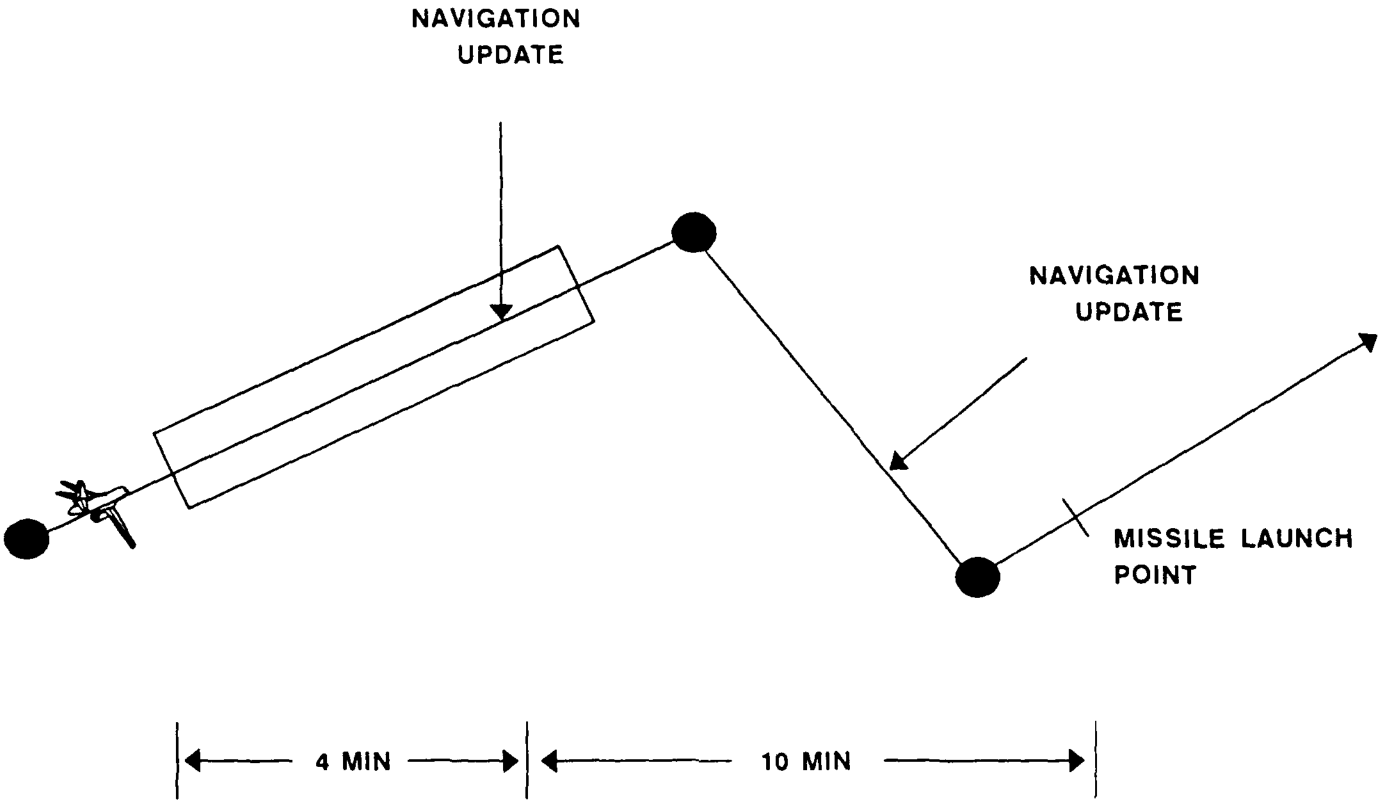


Figure 12. Notional Operational SFFD Scenarios

the target density in the search area and b)that there was the same target density in the search as they had experienced during the SFFD flights. Assuming that there were four actual targets present in the search area, they were asked to rate their expectation that the SFFD system would have allowed them to fire at least two missiles against targets for which they were at least 80 percent confident. They were also asked to projectively provide a SWAT rating (Pro-SWAT) for the workload that they would expect to experience under these more operationally realistic conditions.

OPTIMIZING THE SFFD OI

Recognizing that the SFFD OI was only one of many possible crew system interface concepts for use with SFFD avionics capabilities, the SMEs were asked to comment on four of its major design attributes: display placement, display size, symbology, and format content. They were also solicited to provide written comments (both individually and in the form of a group consensus) as to how they would redesign the SFFD OI to make it better suited to support them in the search, occupancy check, and weapon confirmation tasks.

Section VI

RESULTS

WORKLOAD

Workload (SWAT) ratings were obtained from the seven SMEs immediately after the completion of two distinct SFFD tasks: Pre-IP situational awareness and target confirmation/weapon assignment. SWAT responses from 93 of the SFFD passes were selected. The selection was based on passes in which all SFFD subsystems were in proper operation. (This was done based on the flight logs.) The mean SWAT workload values were computed to be:

	Pre-IP	Target Confirmation/ Weapon Assignment
Mean SWAT (N = 93)	4.6	26.3

Reid and Colle (1988) provide guidance on interpreting SWAT scores. They suggest that a value in the range of 30 to 50 is indicative of a potential workload saturation condition.

PERFORMANCE

Although the SFFD project was intended to be a demonstration of an avionics concept and not an operational assessment of the capabilities of that concept, an indication of the effectiveness of system can provide context within which the SFFD OI can be assessed more realistically. Woolet (1992) presents a preliminary analysis of SFFD system performance. Of the 864

images actually acquired, 186 of them contained actual targets (not including empty nets or vehicles totally masked by terrain or vegetation). The SMEs were able to correctly confirm 117 of these, resulting in a HR of almost 63 percent (117/186). In addition, they incorrectly declared 60 non-target images to contain targets, resulting in a FAR of eight percent (60/[864 - 117]).

SFFD OI ASSESSMENT

Figure 13 A and B presents the mean of the SFFD OI assessment ratings obtained from the seven SMEs in bar graph form. In the rating scale questionnaire and on the Figure, a value of four represents a neutral response on the part of the SME. None of the SFFD OI attributes explored by the rating scale questionnaire received a mean rating of less than 4.6, indicating that the SMSs felt at least mildly positive about that SFFD OI feature.

The three questions which produced the most strongly positive mean SME ratings (i. e., strongest SME agreement) were as follows:

1. FRZ LLS and FRZ FLIR are a strong improvement over "live" video imagery for SFFD target acquisition tasks (mean SME rating = 6.0)
2. The complexity of the SFFD OI controls and displays was at a level acceptable to the operational user community (mean SME rating = 5.9)

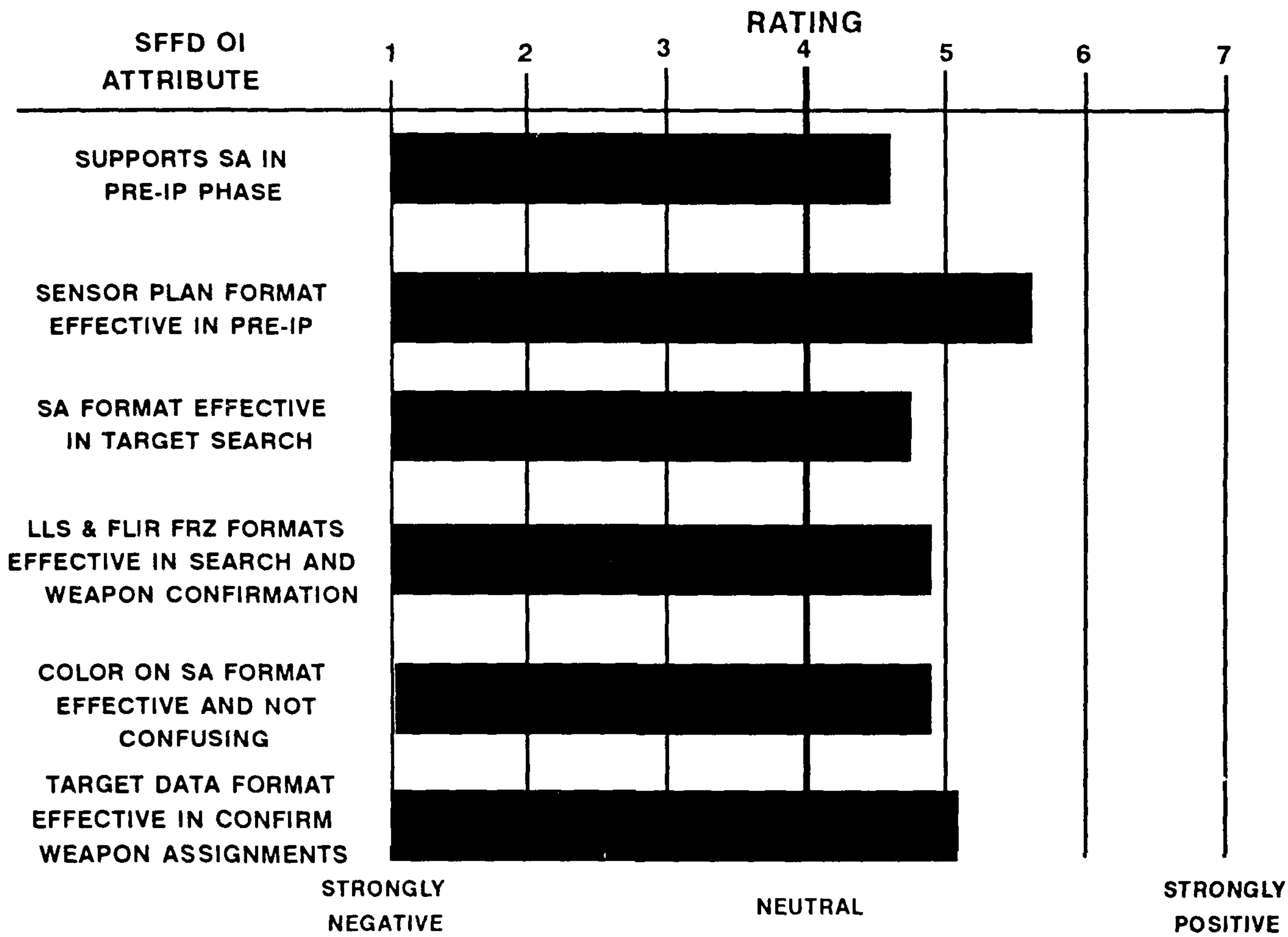


Figure 13A. Results of Rating Scale for Baseline SFFD Operator Interface Design Attributes

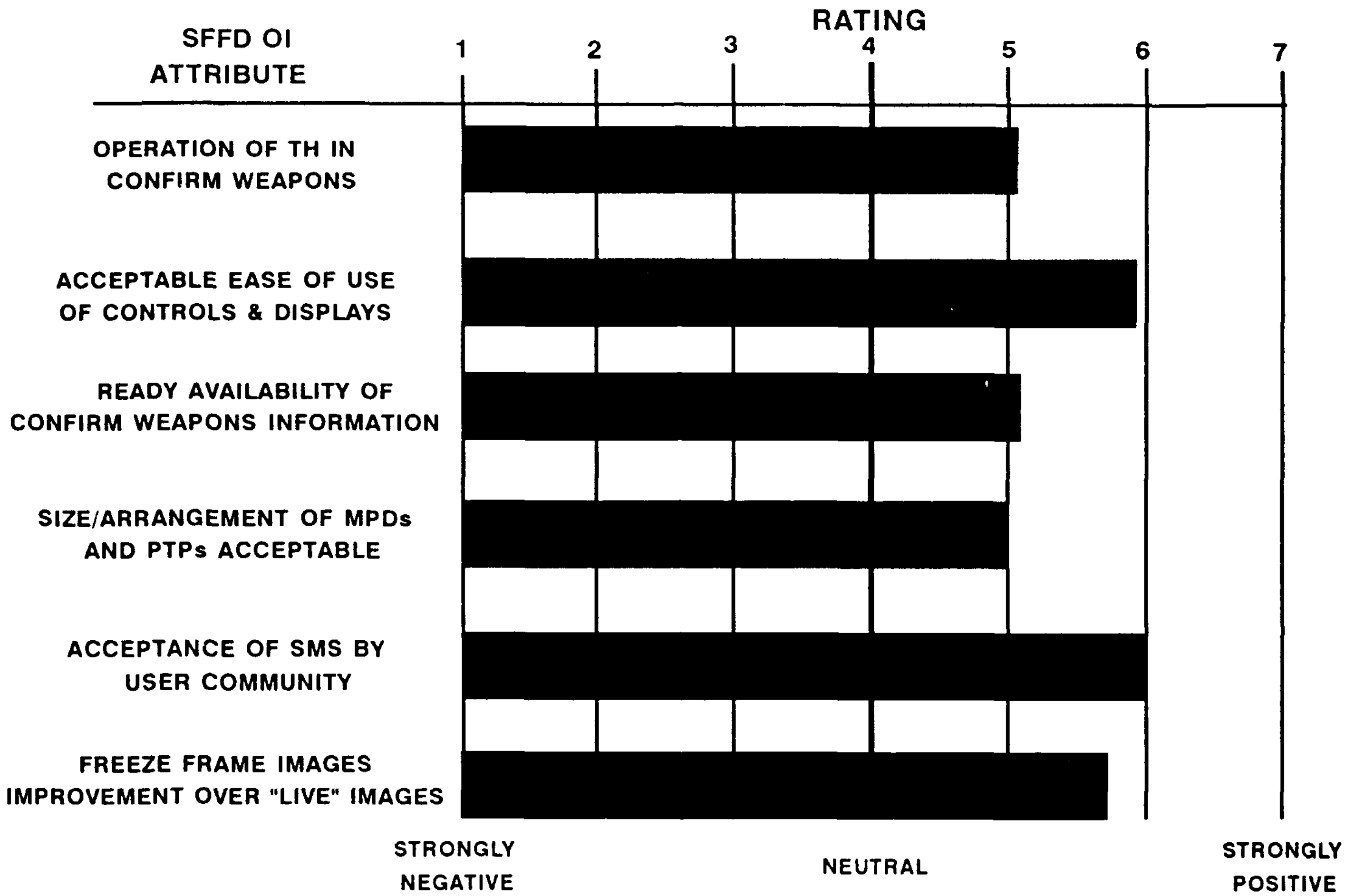


Figure 13B. Results of Rating Scale for Baseline SFFD Operator Interface Design Attributes (Continued)

3. Acceptance of the demonstrated SMS concept by the operational user community (mean SME rating = 5.7)

OPERATIONAL UTILITY ASSESSMENT

For the two target density cases (half and equal), the SMEs *strongly* felt that they would be at least 80 percent confident in being able to search, confirm, and assign weapons against at least two of four possible targets (mean SME ratings = 6.0 and 5.7, respectively). In the case of half the target density but extended search duration, the SMEs expected to experience approximately the same workload (mean SME Pro-SWAT rating = 25.2 [versus mean SME SWAT rating = 26.3]) as encountered during the SFFD flights. For the case of the same target density and extended duration, they expected to encounter a significantly ($p < 0.01$) elevated level of workload (mean SME Pro-SWAT rating = 41.3.

SFFD OI ENHANCEMENTS

The SMEs saw little or no value with regard to adding a counter to tally the number of times an image had been viewed (mean SME rating = 3.8). They did see positive benefit to adding an additional eight image storage buffers for LLS FRZ imagery (mean SME rating = 5.5). They verbally expressed a strong preference for the digitized color photography as an underlay on the SA Display Format screen (verbal comments only).

SFFD OI OPTIMIZATION

Several general observations appeared in the individual and consensus responses to SFFD OI optimization. The SMEs desired to have the OI controls and displays more closely grouped together and integrated within a lower console. (They had to look up to employ MPD 1 and 2 during the flight demonstrations.) They generally desired to have all PTP functions consolidated into an integrated keyboard, located to the left side of the OI console. This was expected to facilitate left hand operation of all task functions requiring keyboard entry while leaving the right hand free for TH functions. (During the demonstration, SMEs had to remove their right hand from the TH to control PTPs 2 and 4 [Figure 5]). They unanimously found the size of the SFFD OI displays (approximately six by eight inches, vertical and horizontal dimensions) to be acceptable. They felt that the capability to declutter the FLIR FRZ was desirable. (They could declutter overlayed symbology from the FLIR FRZ format.) They also strongly desired to have an image "zoom" or magnification capability integrated into the FLIR and LLS FRZ image display formats so that they could manually command an enlargement of the image for suspected targets.

Section VII

CONCLUSIONS

WORKLOAD

The workload levels reported by the seven SMEs who participated in the SFFD project reflected adequate support by the SFFD avionics integration concept (which included both an automated SMS and tailored OI). Workload associated with Pre-IP situational awareness activities was comparable to that frequently found associated with the crew monitoring the automated functioning of a subsystem (e. g., an automated weapon release event). The mean SWAT score associated with the target acquisition tasks, although much higher, was not in the range which would indicate task saturation. Based on these results, the workload found to be associated with the SFFD concept can be qualitatively described as being in the low-to-medium range.

PERFORMANCE

Although not of primary concern in the context in an avionics concept demonstration, the values obtained for the HR (0.63) and FAR (0.08) MOPs are very supportive of the further development of the SFFD concept. These MOPs can be expected to show improvement if SFFD avionics upgrades are made. A first or second generation FLIR can be expected to provide greatly enhanced image quality over the commercial FLIR used in the

demonstration. ATC/ATR technology could be applied to both the LLS and FLIR imaging systems in expectation of reducing the number of non-target images presented to the operator. An image zoom capability could help the operator reduce both the FAR (and the number of missed targets). A "tighter and lower" rearrangement of the OI might reduce operator workload.

SFFD OI

The general findings of the SMEs was that the SFFD OI was both effective and highly acceptable by the user community. Several suggestions (above) for OI improvement were made which might further enhance the effectiveness of the OI.

OPERATIONAL UTILITY

Although the SMEs generally expressed confidence in being able to effectively employ the SFFD avionics capabilities (including the OI) under more realistic operational scenario conditions, the relatively high Pro-SWAT value produced for the high target density, extended duration mission is of some concern. If the SFFD avionics concept is further developed, attention should be paid to reducing crew workload either through additional avionics capabilities or a higher level of crew training.

ENHANCEMENTS

The image review counter was judged to be of little value

and probably should be further pursued in any future development. The addition of LLS image buffers and the use of digitized color aerial photographs as an underlay on the SA Display format screen were both supported by the SMEs and should be seriously considered for incorporation.

OPTIMIZATION

Although the SFFD OI was generally highly acceptable to the SMEs, several suggestions were elicited which might further improve the crew system design. The "tighter and lower" arrangement of the SFFD OI controls and displays and the addition of an image zoom capability are suggested for any further development.

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